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SIMULATION METHODS OF TRANSIENT THERMAL PROCESSES IN GAS-CO OLED REACTORS ON ANALOGUE COMPUTERS

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INTRODUCTION

Recently the analogue and digital computers are frequently used for working out complex automatic control systems,investigation of the accident and start up conditions of atomic power plants [4,5,6].The use of computers is difficult since equations for the subjects under control (in particular,a reactor,heat exchangers) are partial differential equations.

Digital computers permit partial differential equations to be solved.Complicated and long programming process of the problem is a considerable disadvantage of these machines as well as their difficult application to the inve stigation when connecting with real control system elements.

The preparation and treatment of machine equations being simple,it is not difficult for the analogue computers to connect with the real elements of control systems.Serial analogue computers (MN-7, $ЭMУ$-8, $ЭMУ$-10, MH-10, MH-14, MH-8, MH-Б) are however designed to solve usual differential equations.The method for transformation of partial equations with respect to three variables into non-linear differential equations is therefore necessary.

The simulation method of transient thermal processes in gas-cooled reactors on the analogue computers. As is known,transient heat transfer in fuel elements of the reactor in a general form can be presented by partial equations with respect to three variables: the radius of the fuel element,coordinates along the length and time.

A method for averaging of gas and fuel elements *parameters* along the radius
and the reactor length is necessary to transform this equations in-
to ordinary differential equations.

Averaging the temperature distribution of the fuel element along
the radius can be realized after introduction of the power dependence

$$T_{cr}(r) = a + \beta r + c r^2 + \ldots \tag{1}$$

for the set of equations:

$$\frac{\partial T_M}{\partial \tau} = \frac{q_{vi} S_M}{C_M \gamma_M S_M} + \frac{\alpha_r \Pi}{C_M \gamma_M S_M} (T_{Mn} - T_r) \tag{2}$$

$$\frac{\partial T_r}{\partial \tau} = \frac{\alpha_r \Pi}{C_p \cdot \gamma_r \cdot S_r} (T_{Mn} - T_r) - \frac{C_p G}{C_p \gamma_r S_r} \cdot \frac{\partial T_r}{\partial z} \tag{3}$$

where

$\overline{T}_M = T_M$, T_r = mean cross-sectional temperature of fuel element and
respectively;

T_{Mn} = fuel container temperature of the gas side;

q_{vi} = heat flux per unit volume;

γ_r, C_M, γ_M = heat capacity and specific weight of gas and fuel element
material, respectively;

Π, S_r, S_M = channel perimeter, cross-sectional area of gas and fuel ele-
ments;

α_r = individual heat transfer coefficient;

G = gas flow rate.

For a plane wall, δ in width, with the internal sources and one-
sided heat sink with initial condition $\overline{T}_M = \int_0^\delta T_M dy / \delta$ and boundary con-
ditions $\left(\lambda \frac{\partial T}{\partial y} \right)_{y=0} = 0$ and $-\lambda \frac{\partial T_r}{\partial y} = \alpha_r (T_{Mn} - T_r)$, it is obtained that
the thermal resistance of the wall is taken into consideration in the
reduced individual heat transfer coefficient

$$\alpha_{np} = 1 / \left(\frac{1}{\alpha_r} + \frac{\delta}{3\lambda} \right) \tag{4}$$

For rod-type fuel elements of the radius r the reduced individual
heat-transfer coefficient is as follows

$$\alpha_{np} = 1 / \left(\frac{1}{\alpha_r} + \frac{r}{4\lambda} \right)$$

where λ is the thermal conductivity of the fuel element materials,
and the set of equations (2) and (3) becomes

$$\frac{\partial \overline{T}_M}{\partial \tau} = \frac{q_{vi} S_M}{C_M \cdot \gamma_M V_M} - \frac{\alpha_{np} \Pi}{C_M \gamma_M S_M} \cdot (\overline{T}_M - T_r) \tag{2a}$$

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$$\frac{\partial T_r}{\partial \tau} = \frac{\alpha_{np} \, ll}{C_p \, \gamma_r S_r} (\bar{T}_M - T_r) - \frac{C_p \, G}{C_p \, \gamma_r S_r} \cdot \frac{\partial T_r}{\partial Z} \tag{3a}$$

After averaging fuel element and gas temperatures along the radius, the heat-transfer process in the reactor, regenerator and cooler is described by partial differential equations with respect to two variables (time and the coordinate along the length)

It is necessary to find the method for determination of parameters along the reactor length. Averaging temperatures along the reactor length can be presented by the relation between the mean gas temperature and inlet and outlet temperatures

$$T_{rcp} = (T_{2p} + T_3)/2$$

In this case the core must be divided into so many sections along the reactor length that within a section the temperature could be considered linear. However, the finite difference method cannot be recommended for study of dynamics of an atomic power plant, because in this case the sets of equation of the transient heat transfer in the heater and reactor occupy a large part of the machine blocks.

Substitution of the set with distributed parameters by the set with lumped parameters [4,5] is the simplest and widely used method of averaging temperatures along the reactor length. This method is admissible at small diversion of the parameters from their nominal values. Accuracy of the solution is uncertain in the case of greatly changing gas flow rate, thermal capacity of the reactor and inlet gas temperature. When heat exchangers are presented by a set of equations with lumped parameters in the case of great changes of variables (start-up, heating, emergency conditions etc.) the transient process duration is distorted; the number of peculiarities of the heat transfer process is not taken into consideration.

The following averaging gas temperature method permits to obtain an admissible accuracy of simulation with a smaller number of operational amplifiers than in the case of dividing the core into the sections when the difference method is applied [7].

Gas-cooled reactor with rod-type fuel elements. Fig.1 shows the design diagram of the core with the rod-type fuel elements.

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The usual assumptions required for tstudying transient heat transfer between gas flow in the channel and the wall of the channel. with internal sources of variable heating rate are following:

1. Gas subcooling in both bottom and top reflectros is not accounted for.

2. Heat conducted in the wall along the channel is neglected.

3. Experimental individual heat-transfr coefficients of the steady-state flow is used for transient processes.

4. Heat release varies according to a cosine curve along the length of the fuel element.

With these assumptions transient heat transfer in reactor fuel elements is described by the following set of equations:

$$C_m \gamma_m \cdot S_m \frac{\partial T_M}{\partial \tau} = q_{v_o} S_m (\cos \pi \cdot \frac{z}{\ell + 2h}) \bar{N} - \alpha \cdot \Pi \cdot (T_M - T_r) \tag{2b}$$

$$C_p \cdot \gamma_r \cdot S_r \cdot \frac{\partial T_r}{\partial \tau} + C_p G \frac{\partial T_r}{\partial z} = \alpha \Pi (T_M - T_r) \tag{3b}$$

The channel centre is a zero reading along the length.

Initial and boundary conditions are:

$$z = -\ell/2 \qquad T_r (\tau, -\ell/2) = T_{2\rho_0} \qquad \text{at} \quad \tau = 0$$
$$z = \ell/2 \qquad T_r (\tau, \ell/2) = T_{3_0} \qquad \text{at} \quad \tau = 0$$
$$T_r (\tau, -\ell/2) = T_{2\rho}$$

Equations (2b),(3b) are integrated within the limits from $-\ell/2$ to $\ell/2$

$$C_m \gamma_m S_n \frac{d}{d\tau} \int_{-\ell/2}^{\ell/2} T_r(\tau, z) dz = q_{v_o} S_m \bar{N} \int_{-\ell/2}^{\ell/2} \cos \pi \cdot \frac{z}{\ell + 2h} dz - $$
$$- \alpha \Pi \left(\int_{-\ell/2}^{\ell/2} T_M dz - \int_{-\ell/2}^{\ell/2} T_r dz \right) \tag{6}$$

$$C_p \delta_{r c_p} S_r \frac{d}{d\tau} \int_{-\ell/2}^{\ell/2} T_r dz = \alpha \Pi \left(\int_{-\ell/2}^{\ell/2} T_M dz - \int_{-\ell/2}^{\ell/2} T_r dz \right) - C_p G (T_3 - T_{2p}) \tag{7}$$

$(1/\ell) \int_{-\ell/2}^{\ell/2} T_r(\tau, z) dz = T_{r c_p}$ = mean gas temperature along the channel length; $(1/\ell) \int_{-\ell/2}^{\ell/2} T_M(\tau, z) dz = T_{M c_p}$ = mean fuel element temperature along the channel length etc.

Taking into account for these notations, equations (2b) and (3b) become of the form:

$$\frac{d T_{M c_p}}{d\tau} = \frac{2 q_{v_o} V_M}{C_m \gamma_m V_M} \cdot \frac{\ell + 2h}{\pi \ell} (\sin \pi \cdot \frac{\ell/2}{\ell + 2h}) \bar{N} - \frac{\alpha F}{C_m \gamma_m V_M} (T_{M c_p} - T_{r c_p}) \tag{6a}$$

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$$\frac{d T_{rcp}}{d\tau} = \frac{\alpha F}{C_p \gamma_{rcp} V_r} (T_{Mcp} - T_{rcp}) - \frac{C_p G}{C_p \gamma_{rcp} V_r} (T_J - T_{2p}) \tag{7a}$$

where

v = volume of fuel elements or gas per fuel element;

F = heat transfer surface of fuel elements;

Thus for mean temperatures of the gas T_{rcp} and wall T_{Mcp}, ordinary non-linear differential equations are obtained. The analogue computers can be used for their solution.

Let us apply integration by parts within the limits from $-\ell/2$ to $\ell/2$ to integral of the form $\int_{-\ell/2}^{\ell/2} T_r(\tau, z) dz$ to obtain the relation between the mean gas temperature T_{rcp} and the inlet T_{2p} and outlet T_J gas temperatures. As a result of successive integration, the integral can be represented by the infinite series

$$T_{rcp} = \frac{1}{\ell} \int_{-\ell/2}^{\ell/2} T_r(\tau, z) dz = \frac{z}{\ell} T_r - \frac{z^2}{2\ell} \frac{\partial T_r}{\partial z} + \frac{z^3}{6\ell} \frac{\partial^2 T_r}{\partial z^2} -$$

$$- \frac{z^4}{24\ell} \frac{\partial^3 T_r}{\partial z^3} + \frac{z^5}{120\ell} \frac{\partial^4 T_r}{\partial z^4} - \cdots \Big|_{-\ell/2}^{\ell/2}$$

Infinite series (8) may be presented by the general term of the series:

$$T_{rcp} = \sum_{1}^{\infty} \left(\frac{z^n}{n!} \right) \frac{\partial^n T_r}{\partial z^n} (-1)^{n+1} \tag{8a}$$

For this kind of series uniform convergence takes place, if the series $\sum_{1}^{\infty} \frac{z^n}{n!}$ converges uniformly to the set z, and the function $\frac{\partial^n T_r}{\partial z^n}$ (at any z and n) forms the monotonous sequence and at any z and n is limited

$$\left| \frac{\partial^n T_r}{\partial z^n} \right| \leq K$$

But the power series converge at any z (the convergence radius $R = \infty$) /1 - 3/.

The function $T_r(\tau, z)$ is continuous within this series integration limits $-\ell/2 + \ell/2$. Derivatives along the coordinate z $T_r(\tau, z)$ are limited as the heat flux and mean gas temperature are finite (integral (8)). Therefore infinite series (8) is uniformly convergent one, and the solution of the problem may be represented by a few terms of the series expansion of T_r.

(a) One term of series expansion.

$$T_{rcp} = \frac{z}{\ell} T_r \Big|_{-\ell/2}^{\ell/2} = \frac{1}{2} (T_{2p} + T_3) \tag{8b}$$

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Hence $\qquad T_3 = 2\,T_{rcp} - T_{2p}$

A set of equations:

$$\frac{dT_{Mcp}}{d\tau} = \frac{2\,q_{ro}\,V_M}{C_M\,\gamma_M\,S_M}\,\frac{\ell+2h}{\pi\ell}\left(\sin \pi\,\frac{\ell/2}{\ell+2h}\right)\bar{N} - \frac{\alpha F}{C_M\,\gamma_M\,S_M}\left(T_{Mcp} - T_{rcp}\right) \qquad (6a)$$

$$\frac{dT_{rcp}}{d\tau} = \frac{\alpha F}{C_p\cdot\gamma_{rcp}\cdot V_r}\left(T_{Mcp} - T_{rcp}\right) - \frac{C_p\,G}{C_p\,\gamma_{rcp}\,V_r}\left(T_3 - T_{2p}\right) \qquad (7a)$$

$\qquad T_3 = 2\,T_{rcp} - T_{2p}$.

(b) Two terms of series expansion

$$T_{rcp} = \frac{z}{\ell}\,T_r - \frac{z^2}{2\ell}\cdot\frac{\partial T_r}{\partial z} + \dots \Big|_{-\ell/2}^{\ell/2} = \frac{1}{2}\left(T_{2p} + T_3\right) - \frac{\ell}{8}\left[\left(\frac{\partial T_r}{\partial z}\right)_3 - \left(\frac{\partial T_r}{\partial z}\right)_{2p}\right] \qquad (8\,\text{b})$$

The values $\ell\left(\frac{\partial T}{\partial z}\right)_3$ and $\ell\left(\frac{\partial T}{\partial z}\right)_{2p}$ are obtained from equation (3b):

$$\ell\left(\frac{\partial T_r}{\partial z}\right)_3 = \frac{\alpha F}{C_p\,G}\left(T_{M_3} - T_3\right) - \frac{C_p\,\gamma_{r3}\,V_r}{C_p\,G}\,\frac{dT_3}{d\tau}$$

$$\ell\left(\frac{\partial T}{\partial z}\right)_{2p} = \frac{\alpha F}{C_p\,G}\left(T_{M_2} - T_{2p}\right) - \frac{C_p\,\gamma_{r2}\,V_r}{C_p\,G}\,\frac{dT_{2p}}{d\tau}$$

$$T_{rcp} = \frac{1}{2}\left(T_{2p} + T_3\right) - \frac{1}{8}\left[\frac{\alpha F}{C_p\,G}\left(T_{M_3} - T_3 - T_{M_2} + T_{2p}\right) - \frac{C_p\,\gamma_{r3}\,V_r}{C_p\,G}\left(\frac{dT_3}{d\tau} - \frac{\gamma_{2p}}{\gamma_3}\,\frac{dT_{2p}}{d\tau}\right)\right]$$

Hence

$$\frac{dT_3}{d\tau} = \frac{\gamma_{2p}}{\gamma_3}\,\frac{dT_{2p}}{d\tau} + 8\,\frac{C_p\,G}{C_p\,\gamma_3\,V_r}\left(T_{rcp} - \frac{T_{2p} + T_3}{2}\right) + \frac{\alpha F}{C_p\,\gamma_3\,V_r}\left(T_{M_3} - T_3 - T_{M_2} + T_{2p}\right)$$

The set of equations is obtained:

$$\frac{dT_{Mcp}}{d\tau} = \frac{2\,q_{ro}\,V_m}{C_M\,\gamma_M\,V_M}\cdot\frac{\ell+2h}{\pi\ell}\left(\sin\pi\,\frac{\ell/2}{\ell+2h}\right)\bar{N} - \frac{\alpha F}{C_M\,\gamma_M\,V_M}\left(T_{Mcp} - T_{rcp}\right) \qquad (6a)$$

$$\frac{dT_{rcp}}{d\tau} = \frac{\alpha F}{C_p\,\gamma_{rcp}\,V_r}\left(T_{Mcp} - T_{rcp}\right) - \frac{C_p\,G}{C_p\,\gamma_{rcp}\,V_r}\left(T_3 - T_{2p}\right) \qquad (7a)$$

$$\frac{dT_3}{d\tau} = \frac{\gamma_{2p}}{\gamma_3}\,\frac{dT_{2p}}{d\tau} + 8\,\frac{C_p\,G}{C_p\,\gamma_3\,V_r}\left(T_{rcp} - \frac{T_{2p} + T_3}{2}\right) + \frac{\alpha F}{C_p\,\gamma_3\,V_r}\left(T_{M_3} - T_3 - T_{M_2} + T_{2p}\right) \qquad (10)$$

$$\frac{dT_{M_3}}{d\tau} = \frac{q_{ro}\,V_M}{C_M\,\gamma_M\,V_M}\cdot\left(\cos\pi\,\frac{\ell/2}{\ell+2h}\right)\bar{N} - \frac{\alpha F}{C_M\,\gamma_M\,V_M}\cdot\left(T_{M_3} - T_{2p}\right) \qquad (11)$$

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$$\frac{dT_{M2}}{d\tau} = \frac{q_{vo} V_M}{C_M \gamma_M V_M} \left(\cos \pi \frac{\ell/2}{\ell+2h} \right) \bar{N} - \frac{\alpha F}{C_M \gamma_M V_M} \left(T_{M2} - T_{2p} \right) \tag{12}$$

(c) Three terms of series expansion

$$T_{rcp} = \frac{z}{\ell} T_r - \frac{z^2}{2\ell} \frac{\partial T_r}{\partial z} + \frac{z^3}{6\ell} \cdot \frac{\partial^2 T_r}{\partial z^2} - \cdots \bigg|_{-\ell/2}^{\ell/2} \tag{8d}$$

The second derivatives of the temperature are determined by equation (3b)

$$\frac{\partial^2 T_r}{\partial z^2} = \frac{\alpha \Pi}{C_p G} \left(\frac{\partial T_M}{\partial z} - \frac{\partial T_r}{\partial z} \right) - \frac{C_p \gamma_r S_r}{C_p G} \cdot \frac{\partial^2 T_r}{\partial z \cdot \partial \tau}$$

Since the function $T_r(\tau,z)$ is continuous, has all kinds of partial derivatives (they are also continuous) and is defined within the open range $-\frac{\ell}{2} + \frac{\ell}{2}$, the following relation is valid:

$$\frac{\partial^2 T_r}{\partial z \cdot \partial \tau} = \frac{\partial^2 T_r}{\partial \tau \cdot \partial z}$$

Let us denote $\ell[(\frac{\partial T_r}{\partial z})_{2p} + (\frac{\partial T_r}{\partial z})_3] = T'_{rz}$; $\ell[(\frac{\partial T_M}{\partial z})_{2p} + (\frac{\partial T_M}{\partial z})_3] = T'_{Mz}$

Where now T'_{rz} and $T'_{Mz} = f(\tau)$

Substitution of integration limits (into equation (8d)) and simple transformations yield

$$T_{rcp} = \frac{1}{2} \left(T_{2p} + T_3 \right) - \frac{1}{8} \left[\frac{2\alpha F}{C_p G} \left(T_{M3} - T_3 \right) - 2 \frac{C_p \gamma_{r3} \cdot V_r}{C_p \cdot G} \cdot \frac{dT_3}{d\tau} - T'_{rz} \right] +$$

$$+ \frac{1}{48} \left[\frac{\alpha F}{C_p G} \left(T'_{Mz} - T'_{rz} \right) - \frac{C_p \gamma_{rcp} V_r}{C_p G} \cdot \frac{dT'_{rz}}{d\tau} \right] \tag{8e}$$

The set of equations: $\dfrac{dT'_{Mz}}{d\tau} = -\dfrac{\alpha F}{C_M \gamma_M V_M} \left(T'_{Mz} - T'_{rz} \right)$

$$\tag{13}$$

$$\frac{dT'_{rz}}{d\tau} = 12 \frac{dT_3}{d\tau} + \frac{C_p G}{C_p \gamma_{rcp} V_r} \cdot \left[48 \left(\frac{T_{2p} + T_3}{2} \right) - T_{rcp} + \frac{1}{8} T'_{rz} \right] - \frac{\alpha F}{C_p \gamma_{rcp} V_r} \left[12(T_{M3} - T_3) - (T'_{Mz} - T'_{rz}) \right] \tag{14}$$

$$\frac{dT_3}{d\tau} = -\frac{\gamma_{2p}}{\gamma_3} \cdot \frac{dT_{2p}}{d\tau} + \frac{\alpha F}{C_p \gamma_{r3} V_r} \left(T_{M3} - T_3 + T_{M2} - T_{2p} \right) - \frac{C_p G}{C_p \gamma_{r3} V_r} T'_{rz} \tag{15}$$

$$\frac{dT_r}{d\tau} = \frac{\alpha F}{C_p \gamma_{rcp} V_r} \left(T_{Mcp} - T_{rcp} \right) - \frac{C_p G}{C_p \gamma_{rcp} V_r} \left(T_3 - T_{2p} \right) \tag{7a}$$

$$\frac{dT_{Mcp}}{d\tau} = 2 \frac{q_{vo} \cdot V_M}{C_M \gamma_M V_M} \cdot \frac{\ell+2h}{\pi \ell} \left(\sin \pi \frac{\ell/2}{\ell+2h} \right) \bar{N} - \frac{\alpha F}{C_M \gamma_M V_M} \left(T_{Mcp} - T_{rcp} \right) \tag{6a}$$

$$\tag{11}$$

$$\frac{dT_{M3}}{d\tau} = \frac{q_{vo} V_M}{\gamma_M \cdot C_M \cdot V_M} \left(\cos \pi \frac{\ell/2}{\ell+2h} \right) \bar{N} - \frac{\alpha F}{C_M \gamma_M V_M} \left(T_{M3} - T_3 \right)$$

$$\frac{dT_{M2}}{d\tau} = \frac{q_{vo} V_M}{C_M \gamma_M V_M} \left(\cos \pi \frac{\ell/2}{\ell+2h} \right) \bar{N} - \frac{\alpha F}{C_M \gamma_M V_M} \left(T_{M2} - T_{2p} \right) \tag{12}$$

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Analogous sets of equations may be written for 4,5 etc terms of
series expansion.

Results of electronic simulation of transient heat-transfer equations. The above suggested method permits to describe the transient
heat-transfer process in apparatuses with various accuracy depending
on a number of the terms of the series expansion. A larger number
of terms of the series expansion suggests more accurate mathematic
description of the process. However, we obtain the set of differenti-
al equations of a higher order that leads to a sharp increase
of simulating apparatuses. The investigation of transient heat-
transfer process in a gas-cooled reactor under various external
perturbations in case of one, two and three terms of the series
expansion was carried out on the analogue computer of the type
l with the aim to choose an optimal number of terms of the
series expansion. Reactor kinetics have been described by known
equations (4) taking into account the six groups of the delayed
neutrons

$$\frac{dn}{d\tau} = \frac{\Delta K - \beta}{\ell^*} n + \sum_{i=1}^{6} \lambda_i C_i$$

$$\frac{dC_i}{d\tau} = -\lambda_i C_i + \frac{\beta_i}{\ell^*} n$$

where

  n = the neutron density

  Δk = the reactivity

  β_i = the delayed-neutron fraction of the i-group in the total
    number of neutrons

  λ_i = the decay constant of source of i-group delayed neutron

  C_i = the concentration of nuclei-delayed neutron emitters

  ℓ^* = mean neutron life-time.

The effective life-time $l^* = 10^{-5}$ sec and zero temperature co-
efficient for both the fuel and the moderator of the gas-cooled
reactor were assumed.

Verification of the method proposed was carried out for
gas-cooled reactor of an atomic energy plant 50 Mwt in power
with rod-type fuel elemtns. The coolant was nitrogen. Fuel elements
composition $UO_2 + BeO$, moderator was BeO, fuel element coatings
were stainless steel alloys.

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The estimation of the accuracy of the relation T_{rcp} in
terms of inlet and outlet temperatures and their derivatives
along the coordinate z by means of various numbers of tems of
the series expansion of T_{rcp} at stationary and transient condi-
tions for the gas-cooled reactor of the atomic energy plant $N_t =$
50 Mwt was made.

The estimation of the error of the truncated series can be
made with sufficient accuracy by the first term of this series
(1).

In the steady state case the accuracy of the series expan-
sion of the relation T_{rcp} in terms of the inlet and outlet
temperatures and their derivatives can be estimated in the
nominal regime. As calculations showed, two terms of the series
expansion provided sufficient accuracy in the steady-state case
(the error was 1-3 per cent).

The transient conditions of a gas-cooled reactor N_t
50Mwt have been stodied on the analogue computers of type MH6 -1
when T_{rcp} was presented in terms of inlet and outlet temperatu-
res by various number of terms of the series expansion and
by the finite difference method.

Analogue computer MH6 -1 is a block-type arrangement. Ope-
rational amplifiers of this computer have the automatic stabi-
lization of zero level (the modulation-demodulation channel)
and, thus, the little outlet drift (40-60 mkv for 10 min)The
frequency responce of the amplifier is linear in inverted
regime to a frequency of 1000 c/sec. Constant coefficients are
given by the compensating method with an error of 0.2 per cent.
Recording of the resulta is made on the electronic automatic
otentiometer; the frame passes the whole scale for 1 sec. The
tic error of the recorder is 0.5 per cent.

For a gas-cooled reactor on an analogue computer MH6-1
the discontinuous and sinusoidal disturbances separate in each
parameter have been considered at various numbers of term of
the series expansion intgansient heat-transfer equation to de-
termine the limits of validity of this method and the reqired
number of series terms. The results obtained are illustrated in
Fig.s 2-6.

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Fig.2 shows the outlet gas temperature change of the reactor with the discontinuous inlet gas temperature drop by 100°. Two and three terms of the series expansion give practically the same values flask-ups of the inlet gas temperature. One term of the series expansion causes 5-fold excees of the outlet gas temperature flask-up. with such disturbances.

Figs 4 and 3 show the change of the neutron power of the reactor and outlet gas temperature at discontinuous decrease of mass gas flowrate to $G = 0.25$ C_o. Flash-ups of the outlet gas temperature T_{2p} practically coincide with two and three terms of series expansion. The outlet reactor gas temperature flask-up is overextimated 1.4-1.5-fold with one term of the series expansion T_{rcp} .

Under dropping of the safety rods and constant mass-flow rate of a gas and inlet gas temperature of the reactor, the curves of the transient process dor all variables (n, T_{Mcp}, T_3 , T_{rcp}) show a good agreement with each other with 1,2,3 terms of the series expansion T_{rcp}. The mean metal temperature change in this case is shown in Fig.5. Under the reactivity disturbance, the transient heat-transfer process may be described by equation with one term of T_{rcp} expansion in terms of inlet and outlet temperatures.

The following dunamic characteristics of a gas-cooled reactor with a complex of perturbations were studied after researching of individual influence of the disturbances ΔG, ΔT_{2p} , Δk to estimate the accuracy of representation of the transient heat-transfer equations by one, two or three terms of the series expansion:

1. The deep change of the reactor heat power ($\Delta k = -0.005$)
2. Discontinuous decrease of the mass-flow rate of a gas $\Delta G = 0.75 G_o$.
3. Constant discontinuous temperature drop by $100^\circ C$ or 50° increase of inlet gas temperature.

The result of simulation have shown that expression of T_{rcp} in terms of T_{2p} and T_3 by one term of the series expansion under such xomplex disturbances gives essential excess of flask-up of the outlet reactor-gas temperature and 1.3-1.5-fold underestimation of the duration of transient process in comparison with the real values.

Two terms of series expansion of T_{rcp} in terms of T_{2p} and T_3

and their derivatives along the coordinate z provide sufficient
accuracy of the solution under reactor transient conditions (er-
ror is 3-4 per cent).

The same system with the complex perturbation have been
solved numerically by the finite difference method.The results
of this solution are the criterion of corect simulation of the
transient heat-transfer equations with various numbers of the $T_{кр}$
series expansion terms.In the finite difference method,the reac-
tor fule-element length is broken into a few sections.The linear
temperature profile is assumed within each section.

The channel length is broken into a few sections,the number
of which is chosen depending on the required accuracy of the so-
lution (2,4,6 sections).The results of simulation have shon that
division of the fuel element length into 4 sections provides
sufficient accuracy of the solution (error is not more than 1-
3 per cent).The points of control numerical solution by the fini-
te difference method are plotted in Fig.6 which gives a close
agreement with the curves of the solutions for 2 and 3 terms of
the series expansion.

CONCLUSION

The proposed method of simulation of transient heat-transfer
processes in a gas-cooled reactor on the analogue computer takes
into account parameter distribution along the reactor length
by the expression of the integral-mean gas temperature in terms
of inlet and outlet temperatures and their derivatives as
several terms of the series expansion.

The method proposed is verified with deep separate   and
simultaneous disturbances of the gas flow-rate,heat power and
inlet gas temperature.For a gas-cooled reactor of an atomic
power plant two terms of series expansion provide sufficient
accuracy of the solution (error is not more than 3-4 per cent).

The method proposed is compared with another simulation me-
thod - the finite difference method- taken as a reference one
and it is shown that the methos presented is more economic than
the finite difference one (the reactor is described by 5 diffe-
rential equations in comparison with 8 equations in the fnite
difference method).

This method may be used for study of dynamic characteristics
of a reactor with energy change,heating-up starting-up and reac-

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tor shut-down cooling.

The method may be effectively used for study of the dynamic characteristics of a regenerator,cooler and other heat exchangers of nuclear power plants.

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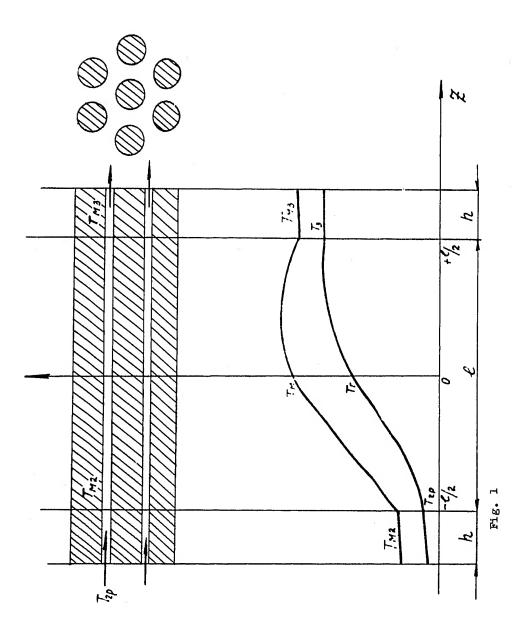4.N.A.Shults,Regulation of Nuclear Power Reactors.Izd.Inostr. Lit (1957).

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FIGURES

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Fig. 1

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Fig. 2

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Fig. 3

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Fig. 4

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Fig. 5

Fig. 6